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Original Article

AN OPTIMIZATION AND INVESTIGATION OF MECHANICAL PROPERTIES AND MICROSTRUCTURES ON FRICTION STIR WELDING OF ALUMINIUM ALLOYS

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ABSTRACT

Now a day for industrial applications and automotive industries, many are utilizing advanced welding technique is Friction stir welding process, offering more advantages are quality of the weld is good, consumption power is low so this process is taken for research work. This paper investigates mechanical properties of input parameters of welding speed, rotational speed, tilt angle, axial force and output parameters are tensile strength, micro hardnesson dissimilar welding of aluminium alloys using welding techniques on friction stir welding process based on cost taguchi L9 is used for carrying research and experiments trailing on parent materials on different ranges of input responses welding speed 60 mm/min., rotational speed 1350 rpm, tilt angle 30, axial force 11 KN with output responses tensile strength 183 Mpa and micro hardness 127 HV are measured with ASTM standards on specimens and analysis are carried out by using grey relational analysis, GRG method and microstructures development done to improve the empirical relations of process are automated and optimized.

KEYWORDS: Industrial Applications, Friction Stir Welding, Aluminum Alloys & Microstructural Investigations

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1. INTRODUCTION

Friction stir welding now a days is widely used in aircraft industries for welding wings, fuel tanks, aircraft structure and marine industries in structure work, automotive industries to weld wheel rims, chassis, fuel tanks, chemical industries for joining pipelines, heat exchanger, air conditioner, electronic industries for joining bus bar, aluminium to copper, connectors, electronic equipment fabrication industries etc. The advantage of friction stir welding is that it can be used to weld both similar and dissimilar metals having no flux and no filler metal [1] Butt Joining of A5754H111 Plates of aluminium on parameters of rotational speed and weld speed on technique of FSW for development of quality for free, defect process on disastrous tests of tensile tests and hardness test, micro analysis on model of simulation and artificial neural network is studied for reliable is good for prediction for industrial applications [2] studied on pure aluminium developments and different applications on Co_2 emissions and economy fuel in manufacturing of aircrafts, space shuttles, ships, trains and vehicles of similar lap and butt weld joints and spot welds of aluminium alloys for greatly used in transportation systems of light, mass production mainly involved significance is consumption of fuel is reduced and laser heat source is assisted with friction stir welding possible of welding of future on thermal stir welding and friction stir spot welding done on materials is

lighter on car bodies of steel replace and bodies riveting airplanes in future. The principle of operation is for without reaching melting point of material for softening tool pin and tool shoulder enable deformation of heat for low plasticized material. The work piece material and rotating tool generates friction and joining the work pieces non consumable tool is used shown in Figure 1. [3,4] Dissimilar joining of AA7075T651 retreating side and AA2024T351 advancing side investigated on the radius of pin flute with rotation speed 900 RPM, weld speed 150 mm/min of maximum tensile strength is 424 Mpa with an efficiency of 94.3 % tool used threaded pin of flat cone for weld strength and joint strength truncated pin threaded tool is used and hardness of the weld is on soft metal of the heat affected zone. Dissimilar joining of aluminium alloys by controlled temperature weld of tensile strength is improved on different clamping materials and backing of specially used for conjunction of weld speed 100 mm/min, rotational speed 900 rpm, tilt angle 3^0 and tensile strength is 426 Mpa, elongation 7.1 % and efficiency of joint strength is 94.8 %.[5,6] studied of 5456-T321 aluminium alloy plates of the lower is 2.5 mm sheet annealed with tools used threaded conical pin, cylindrical conical threaded pin, stepped conical threaded pin, flared triflute pin are used on input parameters of rotational speed 600 rpm and 800 rpm, micro hardness, microstructure on nugget weld, heat affected zone, thermo mechanical affected zone with fine grain size 5 μm with free defect joints with growth of grain are investigated.

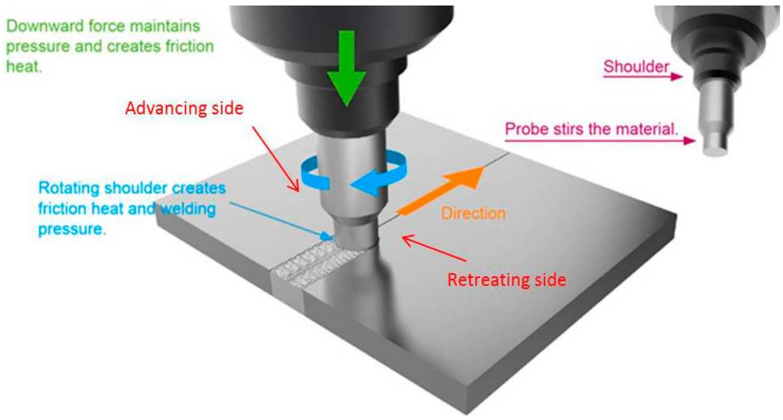


Figure 1: Schematic Diagram of Friction Stir Welding Process

Al6061-T651 and electrolytic tough pitch Cu of 6.3 mm thickness of FSW Joints with process parameters of rotational speed 1500 rpm, weld speed 40 mm/min, tilt angle 2^0 on tensile strength is 133 Mpa and hardness maximum is 188 Hv, elongation 11.5 % presence of joint area has interred metallic compounds of joint is brickle and efficiency is low on specimens of tensile [7]AA6061-T6 Butt joining of 6.35 mm thickness of plates for generation parameters of axial forces, weld speed 600 mm/min is on tensile strength 247 Mpa and maximum of 300 Mpa with Taguchi method and artificial aging of temp is at 160 ^{0}C with 18 h on an area of weld and w-shape micro hardness optimized recently developed on friction stir welding techniques of cnc machines in 3-axis are studied. [8] Investigated dissimilar joints of AA7075-AA6061 advancing side of aluminium alloys of rotational speed 1100 rpm, weld speed 300 mm/min and tilt angle 3^0 on tensile strength is 252 Mpa, efficiency 82 % with different tools tapered and cylindrical, threaded and smooth, non-flatted and flatted of clamping system and backing plate of surface finish is smooth nugget area is wide and coefficient of regression is R_2=0.9851 design of tool is improved by using RSM methodology with central composite design with pin tapered material is poor mixing with joint strength is low. [9] Joining of AA7075T6 of friction stir lap weld of the tool is simulated of welding pitch increased of performance of cyclic and monotonic of micro hardness and shear tests of tensile and metallography shows the thickness of 10 % effective with fatigue life increased to 500 % and observed pin thread damage of welding aluminium alloys no effect on quality of weld. [10] studied of Al2024 and St37 joining of dissimilar

materials with process parameters of rotational speed 224 RPM, 335 RPM, 450 RPM and welding speed 20 mm/min, 25 mm/min, 31.5 mm/min on tensile strength is 331.5 Mpa, efficiency is 85 %, tool pin offset is 0.7 mm and has the inter metallic compounds reduction and microstructural analysis done on scanning electron microscopy, energy dispersive spectroscopy, optical microscope $FeAl_3$ compounds are formed at different phases on stir zone. [11] lap joining dissimilar sheet metals on friction stir forming of AA5052H32 and AA6061T6 with parameters of 500 rpm to 1500 rpm and shear strength is maximum at 6.14 KN and studied of metallography at different zones of thermo mechanically affected zone, stir zone, flow zone of plastically deformed, stir zone of annular and hardness of w-shaped is increased due to stirred effect and generally three failure modes are observed pull out, tear off, delamination of partial bond thinning of sheet upper critical weak zone is formed and contribution is significant. [12] AA5182 and AA6061 with 1mm tick by using technology tailored welded blanks at 45^0 possibility of automobile components for increasing of corrosion resistance, cash worthiness, accuracy and forming of limit curve is lower on base materials and inclination is high on nugget area due to low fracture at this zone. [13] studied different profiles of the pin tip on AA7075T6 alloy with 20 mm thickness of plates with tools conical platform pin tip, taper threaded, square, triangular, three grooves pin tip peak temperature is 50 ^{0}C and high temperatures of 425 and 477 ^{0}C on tensile strength is 310 Mpa and 391 Mpa, elongation 8.3 %, hardness is optimum and grains are finer with aging of natural. [14] joining of friction stir spot welding on Al-Mg-Si alloy of 3mm thickness for body design of modern car by and microstructural analysis done at hook height and area of welds for strengthening of mechanical properties and developing of mathematical model RSM methodology is used for prediction of parameters. [15] The aluminium alloys of 6082T6 on FSW studied Behaviour of material and observed shoulder drove the flow on retreating side and collision of flow at advancing side and tilt angle influence on tool of the shape and the Behaviour of flow at weld nugget zone. [16] studied dissimilar joining of AA6016 and DC04 steel by using conventional techniques of texture, microhardness, grain size and recrystallization avoids micro cracks and defect not observed by using electron base scattered diagram phases and loss of strength in thermo mechanical affected zone and weld zone and coarsening of precipitates occur on prediction of hardness. [17] investigated for joining butt weld of three dissimilar aluminium alloys of 2024T4 and 7475T6, Ti6Al4V with parameters of welding speed of 18 mm/min and 34 mm/min, tilt angle 1^0 and 2^0 on central composite design it shows residual stresses is high and microhardness is low. [18] studied of 6013 and AZ31 on FSW with air conditions under water parameters of rotational speed 1200 rpm and welding speed 80 mm/min on joint strength is improved 152 Mpa and 131 Mpa strength is higher on the joints of the weld. Based on the literature survey, it is found that FSW is the suitable process for getting welds with high quality. But the difficulty is that, as it involves a number of process parameters to be controlled it is always difficult to set the process parameters at the right value in order to get the optimal output. In order to get the optimal values of output, there is a need to find the method which gives the information about the values of input process parameters to be set to get the desired accuracy and output. Hence the present work focused mainly on finding the relationship between the input and output variables, so that the entire process can be further optimized based on this experimental data.

2. MATERIALS AND METHODS

The experiments were carried out Dissimilar Al7075T651 and Al6082T651 aluminium alloys having 6mm thickness of each on a computer numerically controlled Friction Stir Welding it's a special purpose machine done at Annamalai University. The chemical compositions of base material are shown in table 1 and mechanical properties of aluminium alloys are shown in table 2. The plates were finished to a dimension of 100mm × 50mm×6mm. A butt weld is being made by clamping the materials using fixtures by placing AA 7075 and AA 6082 on Advancing Side and Retreating

Side shown in Figure 2 respectively by opting the parametric values are mentioned and using M2Grade SHSS tool of shoulder dia 18 mm and probe length 6 mm. The test specimens are prepared according to the ASTM E8 standards before tensile test specimens are shown in Figure 3 and specimens of tensile test after testing Figure 4. Al7075T651 was placed in the advancing side and Al6082T651 was placed in the retreating side in order to improve mechanical properties of Joint. Based on the literature and previous studies, the parameters with greater influence on the mechanical properties of dissimilar FSW were selected, with their notations and units described in table 3 and experimental design of Taguchi model input parameters and output parameters are shown in table 4. After the welding process, all the welded specimens were cut at transverse sections are appropriately prepared for metallurgical examination. The dissimilar welds of 7075 aluminium alloy and 6082 aluminium alloy was etched with Keller's reagent. Microstructural examination and material mixing observation were carried out using an optical microscope.

Table 1: Chemical Composition of 7075-T651 and 6082-T651 Al Alloys (wt.%)

Elements	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Al
Al7075-T651	0.12	0.2	1.4	0.63	2.53	0.2	0.004	5.62	0.03	89.26
Al6082-T651	1.05	0.26	0.04	0.68	0.8	0.1	0.005	0.02	0.01	97.03

Table 2: Mechanical Properties of Aluminium Alloys

Al alloy	Tensile Strength (MPa)	Micro Hardness (HV)
7075-T651	220	60
6082-T651	330	115

Table 3: The Coded and Actual Values of Input Variables

S. No	Parameters	Notation	Unit	Levels		
				1	2	3
1	Welding speed	WS	mm/min	40	50	60
2	Rotational speed	RS	rpm	1150	1250	1350
3	Axial Force	AF	KN	9	10.5	11

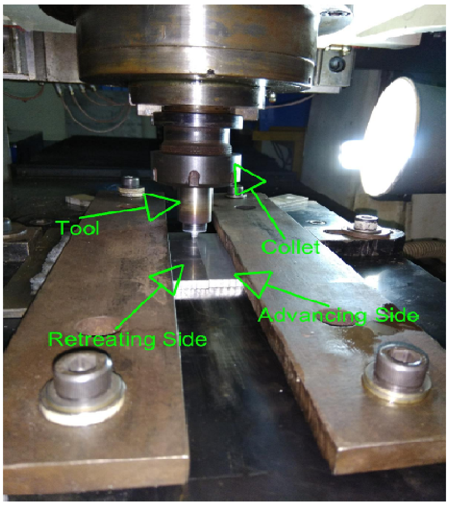


Figure 2: Weld Position of Dissimilar Aluminium Alloys of Friction Stir Welding

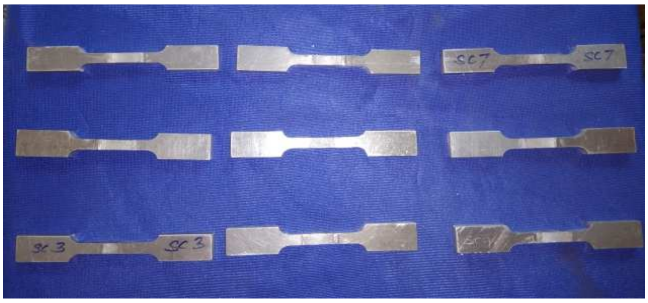


Figure 3: Specimens of Tensile Test before Testing with ASTM E8

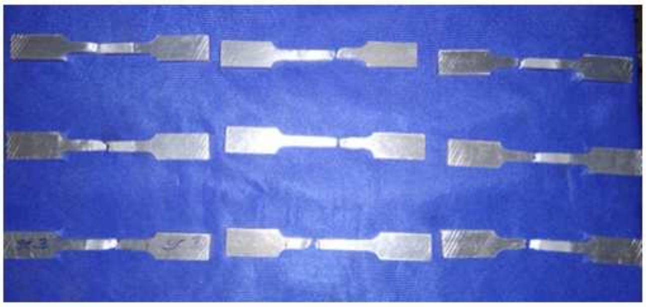


Figure 4: Specimens of Tensile Test after Testing

Table 4: Experimental Design of Taguchi Model

S. No	Welding Speed (mm/min)	Rotational Speed (rpm)	Tilt Angle (^{0})	Axial Force (KN)	Tensile Strength (Mpa)	Micro Hardness (HV)
1	40	1150	1	9	162.3	91
2	40	1250	2	10.5	149.18	110.5
3	40	1350	3	11	166.35	92.5
4	50	1150	2	11	180.87	121.2
5	50	1250	3	9	190.59	110.2
6	50	1350	1	10.5	179.04	113.2
7	60	1150	3	10.5	161.37	111
8	60	1250	1	11	172.35	119.5
9	60	1350	2	9	183.77	127.2

3. TAGUCHI BASED GREY RELATIONAL ANALYSES

The unknown information of a process to determine a system for statistical optimization Techniques. The Taguchi method is a powerful full technique for optimization for different engineering problems. A characteristics of quality can optimize problem by the Technique of Taguchi. The multiple responses of problem optimize inadequate by Taguchi. The analysing and solving of responses, multiple for engineering problems. The steps of GRA Technique as Follows:

- Grey relational generation is also called as original data of normalization.
- Grey relational coefficient compute.
- Grey relational grade compute.
- Finding optimum sequence.
- Analyses of variance.
- Optimal prediction of Grey relational grade.

- Experiment confirmation performance.

3.1. Grey Relational Generation

The analysis of preprocessing data is also called as the generation of grey relation. The relational sequence of data composed values of experiments are form in comparable sequence interval 0 and 1. The three different characteristics quality applied i.e. nominal is better, larger is better, smaller is better most part performed. The original sequence is minimizing ‘smaller the better ‘characteristic used normalize sequence reference.

Selected quality characteristics type is ‘large is better’ with calculation of grey relational generation Equation (1)

$$x_i^*(k) = \frac{x_i^0(k) - \min x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \tag{1}$$

Although $x_i^0(k)$ of series max$x_i^0(k)$ as well as min $x_i^0(k)$ is max together with min series of values, $x_i^*(k)$ after data processing generation of sequence. i=1,2,3….m and k=1,2,3…. n, data of experimental is n and experiments of m.

3.2. Coefficient of Grey Relation

For Normalizing process of coefficient of grey relational is calculated as identify relationship between comparability sequence and reference sequence. Grey relational coefficients calculated corresponding variations considering Equations (2) and (3).

$$\Delta_{0i}(k) = \left| x_0^*(k) - x_i^0(k) \right| \tag{2}$$

$$\zeta_i(k) = \frac{\Delta_{min} + \zeta.\Delta_{max}}{\Delta_{0i}(k) + \zeta.\Delta_{max}} \tag{3}$$

Where $\Delta_{0i}(k)$ series of variation and series of relation $x_i^0(k)$ series of interference$x_i^0(k), \zeta$ identification coefficient, which generally 0.5 parameters are weight age equal. Grey relational coefficient experiment are calculated by orthogonal array of L9 of equation (3).

3.3. Grey Relational Grade

For compatibility series and reference series grey relation grade performed for calculate strength relationship and values are 0 and 1. The GRG has better relation for higher value. Generally, for calculating grey relation grade is grey relational coefficient average summation of equation (4).

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \zeta_i(k) \tag{4}$$

Although γ_i is grey relational grade execution of characteristics of number n experiment i^{th}. The normalized or ideal value are closer to experimental results and correspondence to GRG of larger value.

3.4. Parameter Prediction for Optimal Value

The effects of different parameters are calculated and best response of grey relational grade are closer as a 1 and optimal welding condition of parameters has highest mean GRG value.

3.5. ANOVA Performance

Statistical significance of different parameters for performance of ANOVA probability p value is used and contribution of parameter response can resolute results of ANOVA.

3.6. Prediction Parameters for Optimal Level

The optimal level of different parameters for resolution of prediction of GRG value by using equation (5)

$$\gamma_e = \gamma_m + \sum_{i=1}^{q}(\overline{\gamma_i} - \gamma_m) \tag{5}$$

Although γ_m is mean total of GRG, q is parameters number, $\overline{\gamma_i}$ is GRG mean value of optimal level qth parameter.

3.7. Signal-to-Noise Ratio

Table 4 represents responses of average values of input parameter settings. The responses of three parameters are calculated by signal-to-noise ratio. Higher values of Tensile strength, Elongation, Impact strength gives better performance of welding. The equation (6) is a signal-to-noise ratio for calculation. The mechanical testing executed on three responses. The testing results of FSW joint of ratios S/N shown in Table 5.

$$\text{Signal-to-noise ratio } = -10log_{10}\left(\frac{1}{n}\right)\sum_{i=1}^{n}\frac{1}{y^2{}_{ijk}} \tag{6}$$

Although experimental reproduction of n number and Y_{ijk} variable response of i^{th} characteristic execution of experiment j^{th} experiment with trail k^{th}.

Table 5: Responses of Signal-to-Noise-Ratios

Exp no	Raw data for responses						S/N Ratios	
	T1	T2	T3	M1	M2	M3	S/N_{TS}	S/N_{MH}
1	163	162	165	93	91	89	44	39
2	147	149	152	108	110	112	43	40
3	164	166	168	94	92	90	44	39
4	182	180	178	123	121	19	45	41
5	188	190	192	112	110	108	45	40
6	181	179	177	115	113	111	45	41
7	163	161	159	113	111	109	44	40
8	174	172	170	117	119	121	44	41
9	185	183	181	129	127	125	45	42

3.8 Sequence Deviation and Data Processing Calculation

The analysis part for S/N ratio normalize value for response Equation (1) and S/N ratios is given in Table 5. For calculations of coefficient of grey relation, sequences deviation determined. The calculations are discussed shown in Table 6.

Table 6: Sequence Variation and after Processing Data Responses in Series

Ref. Seq				
	Processing Data after Series		Reponses of Series Variation	
Exp. No	Tensile Strength	Micro Hardness	Tensile Strength	Micro Hardness
	1.000	1.000	1.000	1.000
1	0.344	0.028	0.655	0.999
2	0.970	0.579	0.999	0.420
3	0.444	0.049	0.555	0.950
4	0.786	0.855	0.213	0.144
5	1.000	0.571	0.030	0.428
6	0.744	0.651	0.255	0.348
7	0.320	0.593	0.679	0.406
8	0.589	0.813	0.410	0.186
9	0.851	0.999	0.148	0.858

3.9 Grey Relational Coefficients and Grades Estimation

The estimation of GRCs by Equation (3) sequences deviation shown in Table 6. The ζ characteristic are designate value as 0.5 and performances of trademark and equation (3) is calculated by grey relation coefficients for estimated values GRCs and GRGs shown in Table 7.

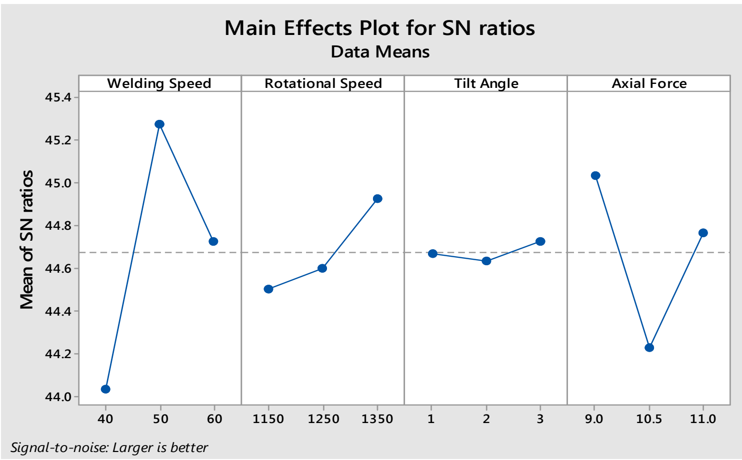
The GRCs values of nine experiments calculated by Equation (1). The characteristics performance of GRGs determines in Equation (4). The characteristics performance of weightage tensile strength, elongation, impact strength is 0.5, 0.3, and 0.2.

Table 7: GRGs and GRCs of Estimation

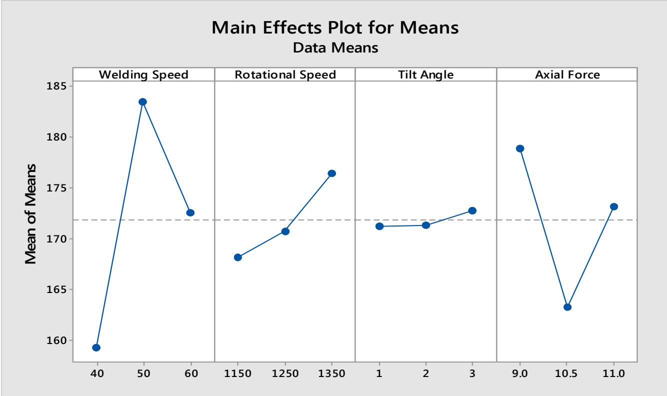
Exp. No	Coefficient of Grey Relation		GRG	Rank
	Tensile Strength	Micro Hardness		
1	0.432	0.333	0.094	8
2	0.333	0.543	0.091	9
3	0.473	0.344	0.101	7
4	0.700	0.776	0.168	3
5	1.000	0.538	0.202	1
6	0.662	0.589	0.149	4
7	0.423	0.551	0.107	6
8	0.549	0.728	0.14	5
9	0.770	0.999	0.195	2

3.10 Input Parameters of Optimum Levels Estimation

The process parameters of each level for calculation of tensile strength is 1.000 and GRG maximum 0.202 of rank 1 has considered on welding speed WS 60mm/min, rotational speed RS 1350 rpm, and tilt angle TA 3^0axial force 11 KN are better characteristics performance of S/N ratios shown in Plot 1 and mean shown in Plot 2. During the welding process of joint of oxidation of Al in Mg of base metal and joint, fractured of a tensile test specimen on welding has high velocity and tool shoulder of beneath due to frictional heat is not sufficient for the plasticized materialon around a probe and work pieces are welded good property. Tilt angle and axial force has positive effect on increases of tensile strength and plastic flow of material on shoulder is uniform and microstructure symmetric form different zones.

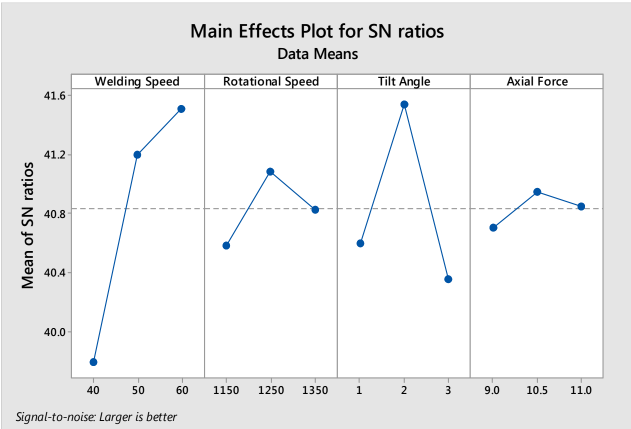


Plot 1: Effects for Signal to Noise Ratio of Tensile Strength

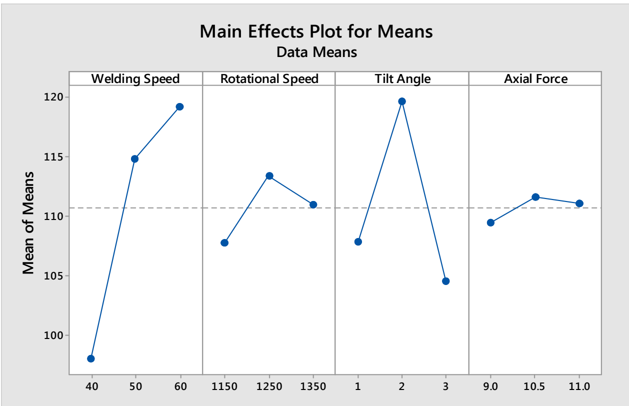


Plot 2: Effects for Means of Tensile Strength

The process parameters of each level for the calculation of micro hardness is 0.999 and GRG maximum 0.202 of rank 1 has considered on welding speed WS 60mm/min, rotational speed RS 1250 rpm, and tilt angle TA 2^0 axial force 10.5 KN are better characteristics performance of S/N ratios shown in Plot 3 and mean shown in Plot 4. The weld zones of heat generation increases of stress flow reduce on the plasticized metal on both advancing side and retreating side due to higher axial force weld joint is higher on micro hardness.



Plot 3: Effects for Signal to Noise Ratio on Micro Hardness



Plot 4: Effects for Means on Micro Hardness

4. METALLOGRAPHY INVESTIGATIONS

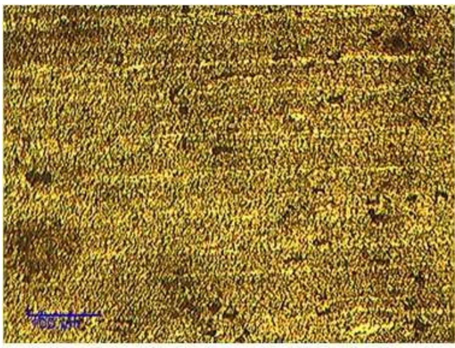


Figure 5a: AA 6082 in Cold Rolled Condition

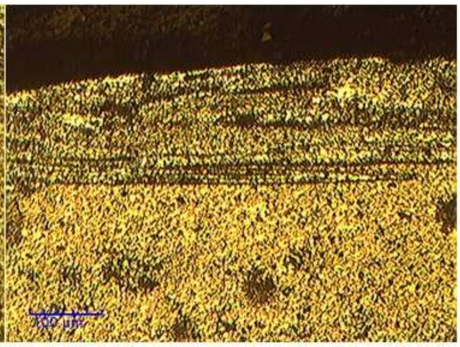


Figure 5b: Shoulder Zone of Eutectic Constituents

Figure 5c: Heat Affected Zone of AA 6082

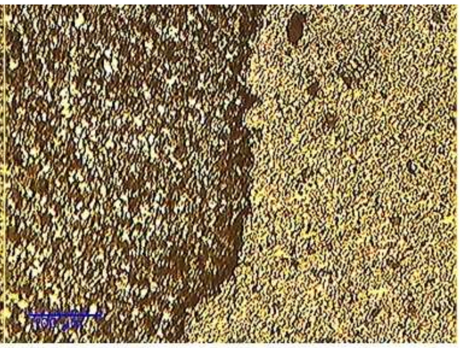


Figure 5d: Interface Zone of AA6082

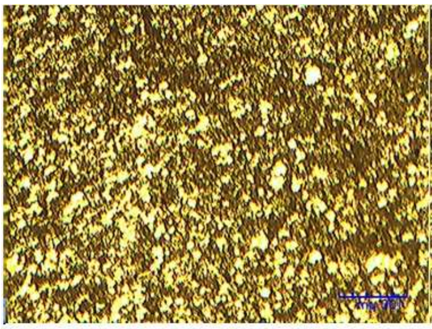


Figure 5e: Central Zone of Nugget

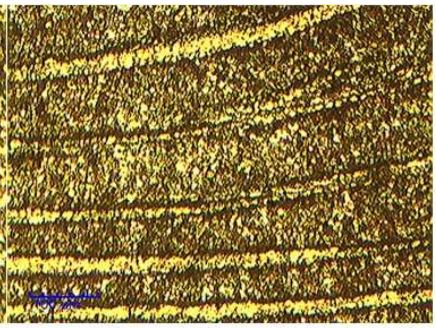


Figure5f: Nugget Zone Bottom

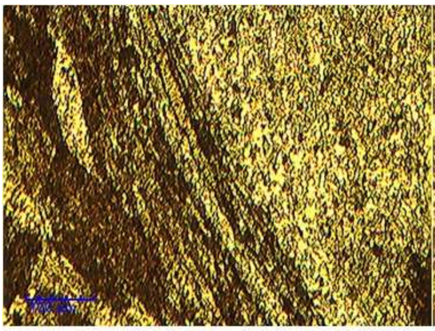


Figure 5g: Interface ZONE of Nugget and AA7075

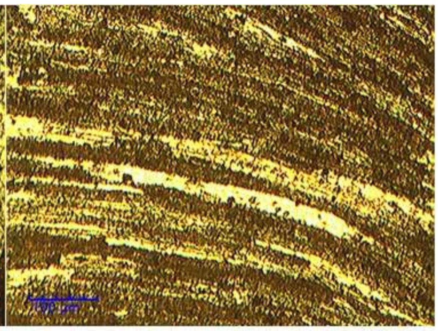


Figure 5h: TMT zone of the AA 7075

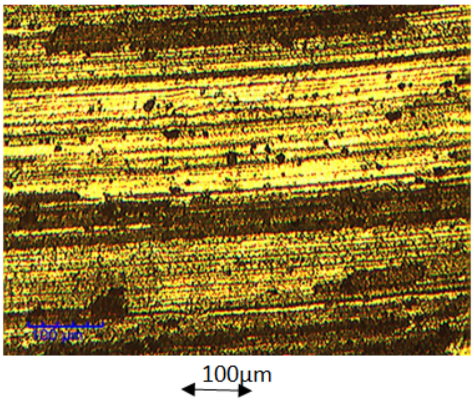


Figure 5i: AA 7075 Parent Metal at Advancing Side

Figure 5: Metallography Investigations of Different Zones

Figure 5 shows microstructures of magnification 100 x and etchant hydrofluoric solution are used Figure 5a shows the microstructure of AA 6082 in cold rolled condition with grain orientation along the direction of rolling with eutectic and insoluble constituents. Figure 5b shows the shoulder zone of the FSW process and the metal matrix undergone fragmentation due to the stirring and the frictional heat of the process facilitated the dissolution of the eutectic constituents of both 7075 and 6082. Alternate layers of 6082 and 7075 constituents undergone fragmentation and re-crystallization. Figure 5c shows the Heat affected zone of AA 6082 close to the nugget zone with grain orientation with formation of TMT ring at the top and bottom of the zone. Figure 5d shows the interface zone of the AA6082 and the nugget zone at the bottom of the fsw zone. Figure 5e shows the central zone of the nugget. The central zone showed well re-crystallized grains and effective re-crystallization taken place due to the conducive temperature existed. The grain size in Figure 5e has 20 microns and no grain orientation. Figure 5f shows the nugget zone bottom with good grain flow of both 7075 and 6082 constituents leading to the formation of alternate fusion lines. Figure 5g. shows the interface zone of the nugget and the AA 7075 at the left side and nugget at the right side. Grain orientation of the 7075 towards upwards observed at the interface. Figure 5h shows the TMT zone of the AA 7075 where the heat of the process increases the plasticity of the parent metal and metal undergone plastic deformation in the direction of tool. The flow of grains shows higher plasticity caused due to higher temperature at this zone due to mechanical parameters. The eutectic constituents have also undergone deformation. Figure 5i shows microstructure of AA 7075 parent metal at the advancing side of the FSW process. The parent metal shows microstructure in rolled temper condition. The sheet has been cold worked by rolling process, and the primary grains of alpha aluminum are elongated along the direction forming. The eutectic constituents like $Cu\text{-}Al_2$, Mg_2Si, $Zn\text{-}Al_2$ and $Mg\text{-}Al_2$ precipitated along the rolling direction and elongated.

5. CONCLUSIONS

In this work, the important weld strength characteristics i.e. Of aluminium alloys with welding speed, rotational speed, tilt angle, axial force of input parameters gets good response on tensile strength and micro hardness is analysed after conducting experiments using the Friction Stir welding setup. The experiments are based on Taguchi L9 orthogonal array design. In order to understand the influence of input process parameters with, welding speed 60 mm/min, rotational speed 1350 rpm, tilt angle 3^0, axial force 11 KN of input parameters get good response on the output responseson tensile strength 190 Mpa and micro hardness 127 HV, 2d plots are plotted for the average values. The 2d plots are analysed and found that the selected input process parameters are influencing over the output responses. The individual graphs presented give the exact trend between the inputs and the outputs. The results presented in the work are analyzed on the basis of analysis

process conducted with microstructures with different zones on thermo mechanical treatment zone has higher plasticity due to eutectic constituents Cu-Al precipitation on rolled condition and parent metal has rolled temper condition. Alternate layers of 6082 and 7075 constituents undergone fragmentation and re-crystallization. Heat affected zone of AA 6082 close to the nugget zone with grain orientation with the formation of the TMT ring at the top and bottom of the zone used for finding the optimal process parameterstogether best output characteristics of welded joints and problem solved by using an optimization algorithm after formulating the objective function. The entire process is automated which helps to increase the production rate without increasing the unit cost of the welded joints.

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